SEP 11 1981

GUIDEWAY DESIGN GUIDELINES

HAMILTON-WENTWORTH RAPID TRANSIT PROJECT

Prepared By: ABAM Limited

For Submission By: Metro Canada Limited

To: The Regional Municipality of Hamilton-Wentworth

URBAN DOCUMENTATION CENTRE
RESEARCH UNIT FOR URBAN STUDIES
McMASTER UNIVERSITY
HAMILTON, ONTARIO

MCL Report HW-1-11.1
Part of Task 4.7
March 11, 1981

004757

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March 11, 1981

Mr. M.M. Ross
Project Co-Ordinator
Rapid Transit Project
100 Main Street East
Hamilton, Ontario
L8N 3V9

Dear Mr. Ross:

Subject: Report HW-1-11-1
Guideway Design Guidelines

We are pleased to submit Report HW-1-11-1, Guideway Design Guidelines. This report is submitted in accordance with the requirements described in Task 4.7 (Sub-section 4.7 of Schedule A to the UTDC - Region Pre-implementation Program Contract). This report has been prepared under Metro Canada direction by ABAM Limited and will, in its final issue, form an important part of the Preliminary Design Standards for the Hamilton-Wentworth ICTS facility.

The Guideway Design Guidelines report is a "living" document. As structural analysis proceeds here in Hamilton, in Kingston and in Federal Way and as guideway conditions specific to Hamilton are identified, this document will be updated. Those revisions and updates will be distributed at key points in the Pre-implementation Program.

You will already be familiar with some of the data contained in this report, as it has been the basis of some of the discussions of the Operations Advisory Committee. In addition, this data is being used by our Planning and Engineering sub-consultant teams for their work.

We have enclosed with this letter one bound copy for your use, and one unbound copy suitable for reproduction.

Very truly yours,

P.J. McCann
Project Manager

PJM:jp

cc: C.T.C. Armstrong
Encl.

INTRODUCTION

Intermediate Capacity Transit System (ICTS) is a technology developed for application in urban settings. Designed for a capacity of 5,000-25,000 passengers per hour per direction, operations are with train consists of up to 4 cars. System features include a steel wheel/steel rail suspension on standard guage continuously welded track, linear induction motor propulsion, steerable axle trucks and moving block automatic train control.

The guidelines presented in this document are provided for use in the preliminary analysis and design of the guideway for the Hamilton-Wentworth Rapid Transit project. The data in this document are based on information obtained from successful demonstration of the ICTS at the Transit Development Centre in Kingston, Ontario.

The Urban Transit Development Corporation is conducting a continuous program of review and improvements to the ICTS. The objective of this program is to further reduce the capital cost of the system, reduce the operation and maintenance costs, and to improve installation capability. Consequently, cost, technical and operational considerations produce revisions in the guideway structure and the guideway configuration.

This document recognizes that system enhancement is essential to provide the most cost-effective transportation system. These design criteria have been prepared anticipating that numerous revisions will be forthcoming. A master copy of the document is maintained at the Hamilton-Wentworth Rapid Transit Project office. Any revisions will be issued to all parties on the distribution list. Verification that current revisions are incorporated in your volume may be made by contacting:

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4.0 Definitions

Geometrics

A	Angle of superelevation, (tan A) is percent of superelevation
a_l	Lateral acceleration
a_v	Vertical acceleration
g	acceleration due to gravity (9.807 m/s)
g_r	rail gage (1.435 m)
j_l	Lateral jerk
j_v	Vertical jerk
L_h	Length along horizontal spiral
L_{sh}	Horizontal spiral length
L_{sv}	Vertical spiral length
L_v	Length along vertical spiral
R_{ch}	Horizontal curve radius at the end of a spiral
R_{cv}	Vertical curve radius at the end of a spiral
R_h	Horizontal curve radius
R_v	Vertical curve radius
V	Vehicle velocity
y	Horizontal spiral offset
z	Vertical spiral offset

5.0 GENERAL REQUIREMENTS

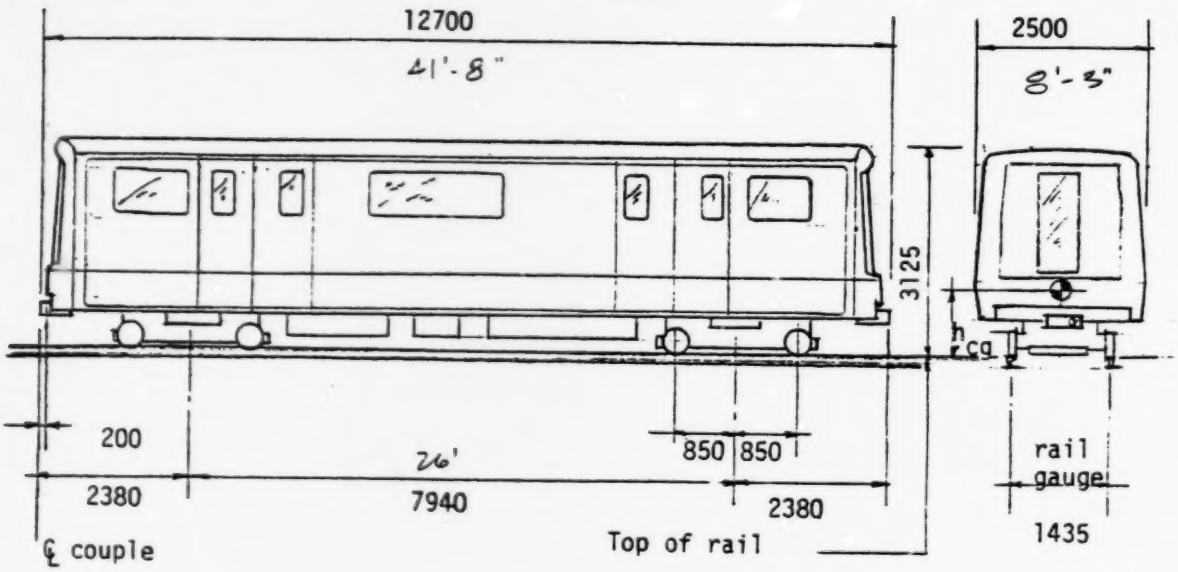
5.1 GENERAL CONFIGURATION

INTRODUCTION

This chapter provides the overall dimensions of the vehicle and guideway for the ICTS application in Hamilton. Vehicle sizes and weights are presented first. Guideway dimensions, system components, vehicle separation distances, station platform elevations and other geometric definitions and constraints are presented in tables and sketches.

Guideway sizes and dimensions are based on the demonstration facility in Kingston. These sizes and configurations have demonstrated that all system requirements and objectives have been satisfied. These requirements include vehicle support, systems integrations, structural dynamics, ground vibration and noise suppression.

TYPICAL VEHICLE DIMENSIONS AND WEIGHTS



Load Condition	Load Symbol SIV	Vehicle Load kN (K)	Axle Load kN (K)	Vertical Center of gravity above top of running rail -mm-
Snow and ice on vehicle	SIV	17.7	-	
Vehicle empty	L_e	133.4 (30.0)	33.4 (7.5)	865
Vehicle empty + snow and ice on vehicle	L_e+SIV	151.1 (34.0)	37.8 (8.5)	876
Normal load (76 pass)	L_N	185.5 (41.7)	46.4 (10.4)	1053
Normal load (76 pass) (76 pass) + snow and ice on vehicle	L_N+SIV	203.2 (45.7)	50.8 (11.4)	1051
Crush load (108 pass)	L	207.5 (46.7)	51.9 (11.7)	1117
Crush load (108 pass) + snow and ice on vehicle	L+SIV	225.2 (50.6)	56.3 (12.7)	1110

TYPICAL GUIDEWAY DIMENSIONS

The ICTS guideway has both elevated structures and at-grade sections. The elevated guideway, dual-lane (Figure 5.1.1) and single-lane (Figure 5.1.2) consists of concrete beams, crossheads and columns. The at-grade sections of the guideway (Figure 5.1.3) are designed as continuously reinforced concrete pavement.

The guideway components are dimensioned in the following figures:

beams:	Figures 5.1.4 - 5.1.5
crossheads:	Figures 5.1.6 - 5.1.9
columns:	Figure 5.1.10

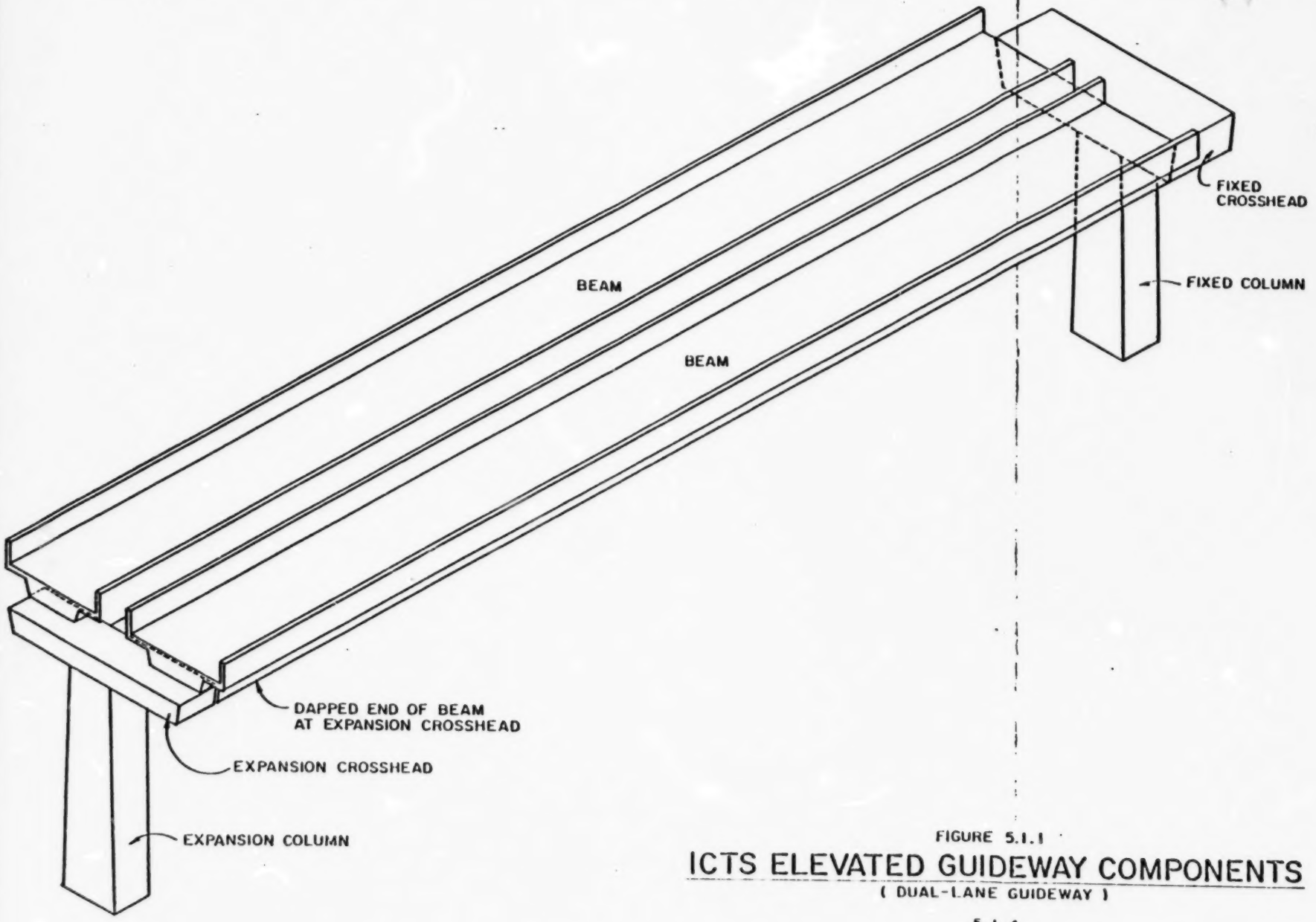


FIGURE 5.1.1

ICTS ELEVATED GUIDEWAY COMPONENTS

(DUAL-LANE GUIDEWAY)

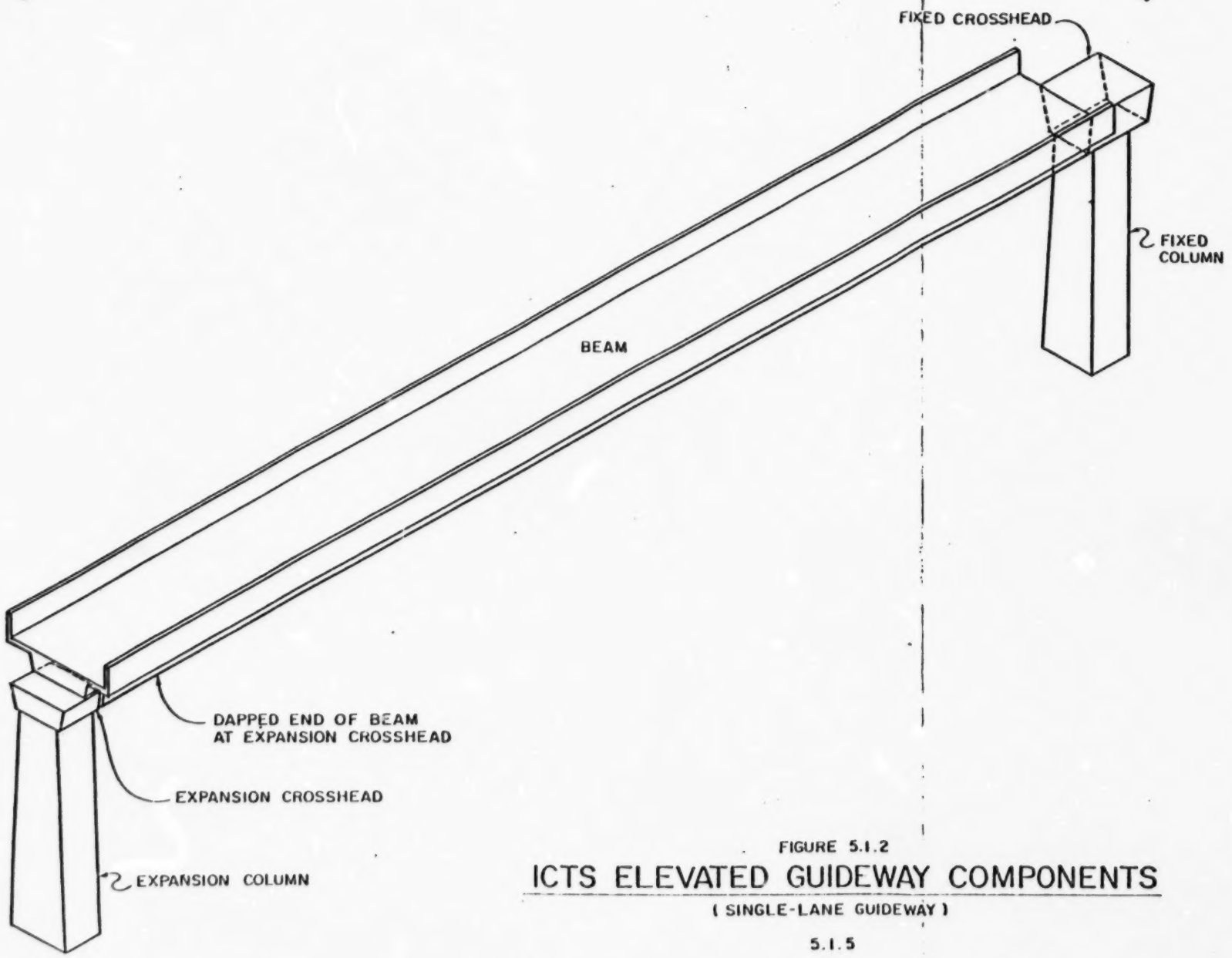


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FIGURE 5.1.2

ICTS ELEVATED GUIDEWAY COMPONENTS

(SINGLE-LANE GUIDEWAY)

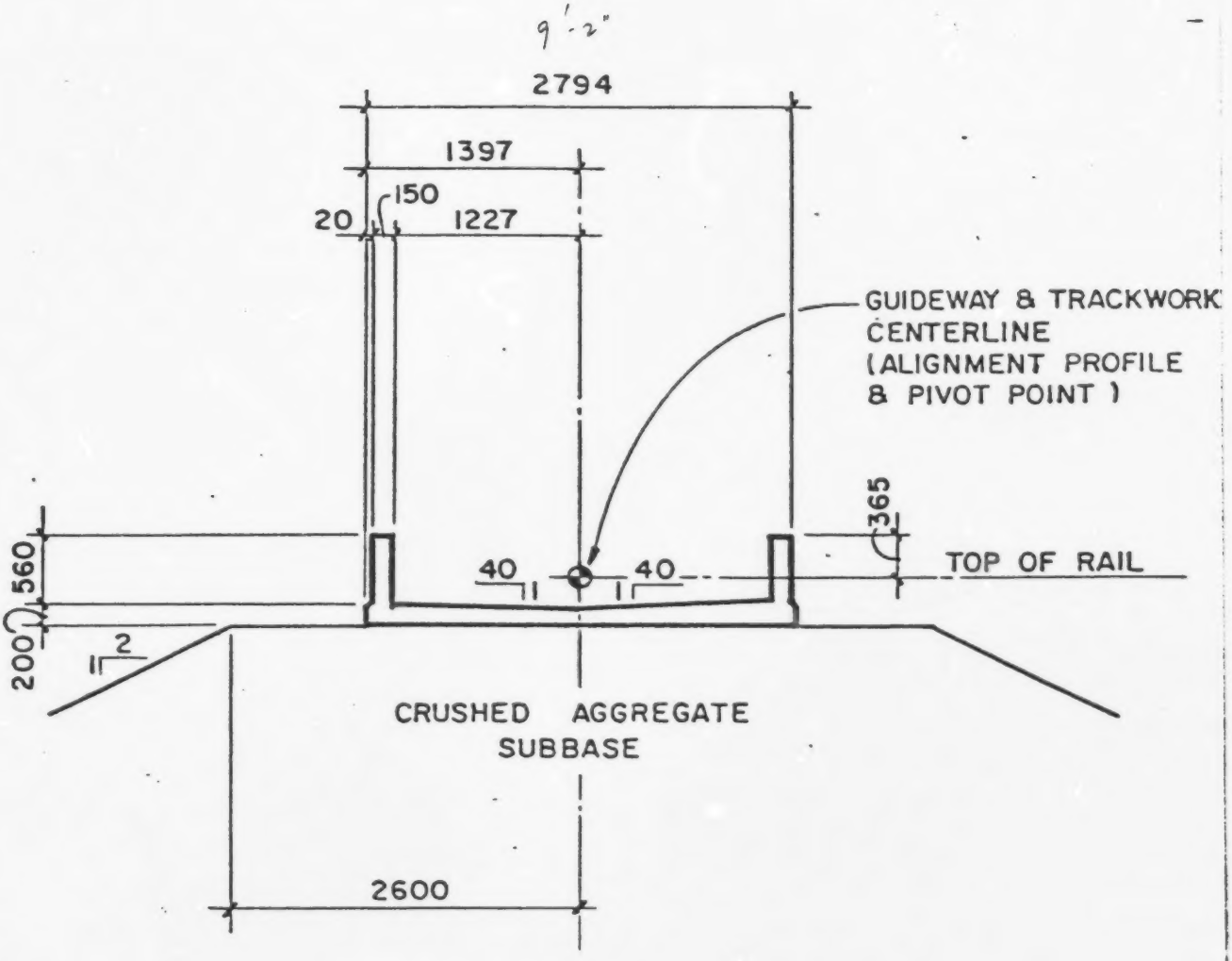


FIGURE 5.1.3

AT-GRADE GUIDEWAY

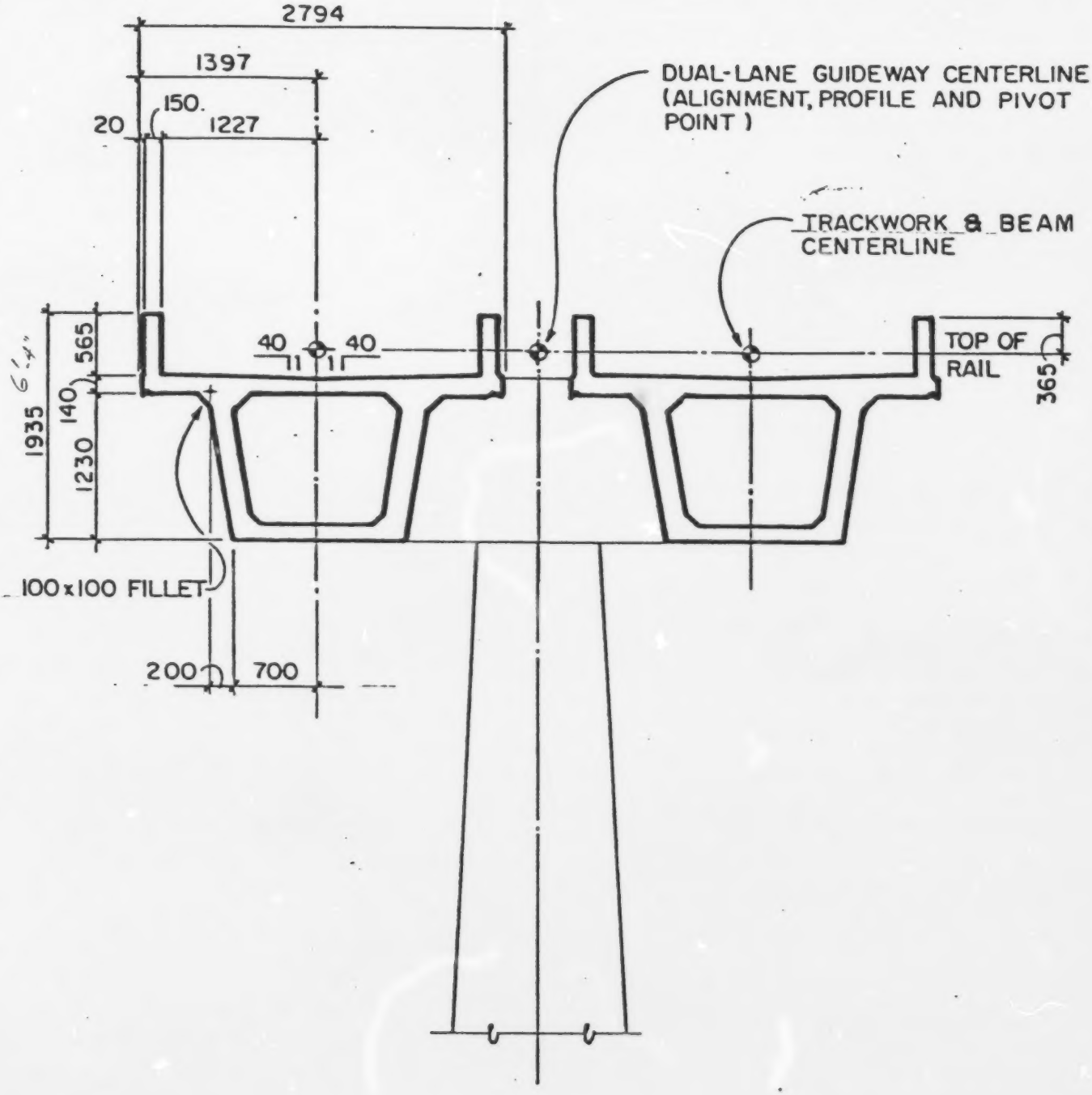


FIGURE 5.1.4

GUIDEWAY BEAM DIMENSIONS

(DUAL-LANE)

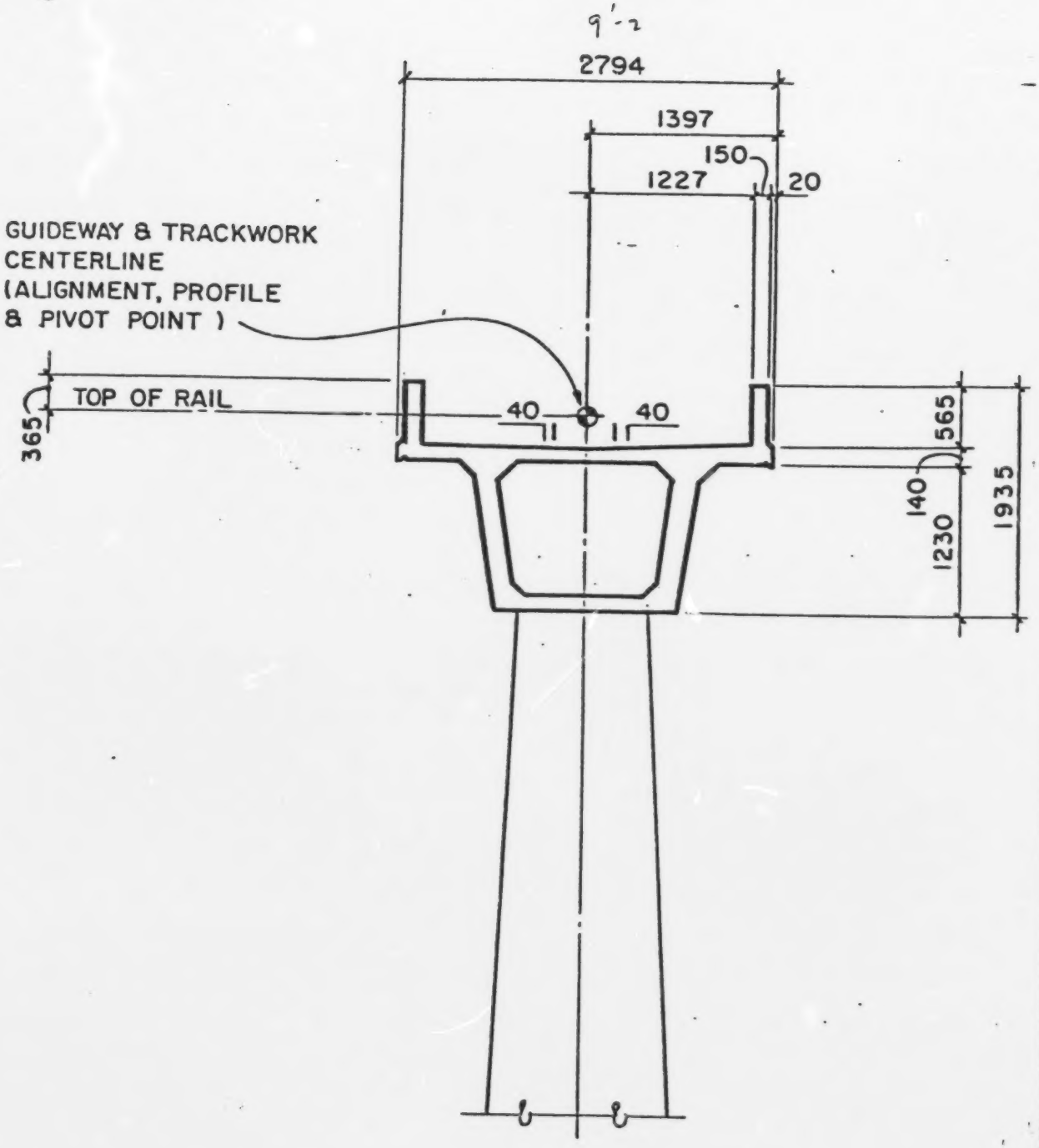


FIGURE 5.1.5

GUIDEWAY BEAM DIMENSIONS

(SINGLE - LANE)

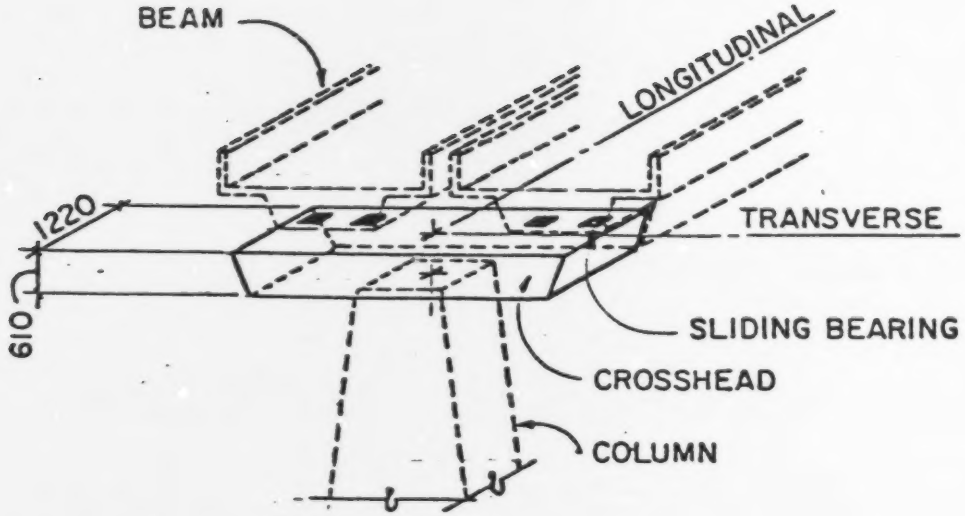


FIGURE 5.1.6

EXPANSION CROSSHEAD

(DUAL- LANE)

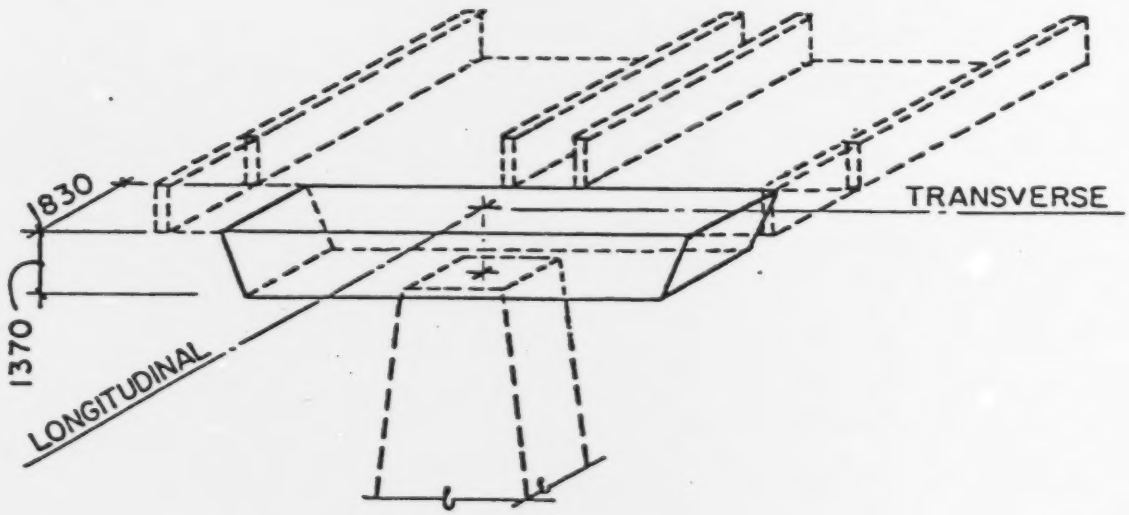


FIGURE 5.1.7

FIXED CROSSHEAD

(DUAL- LANE)

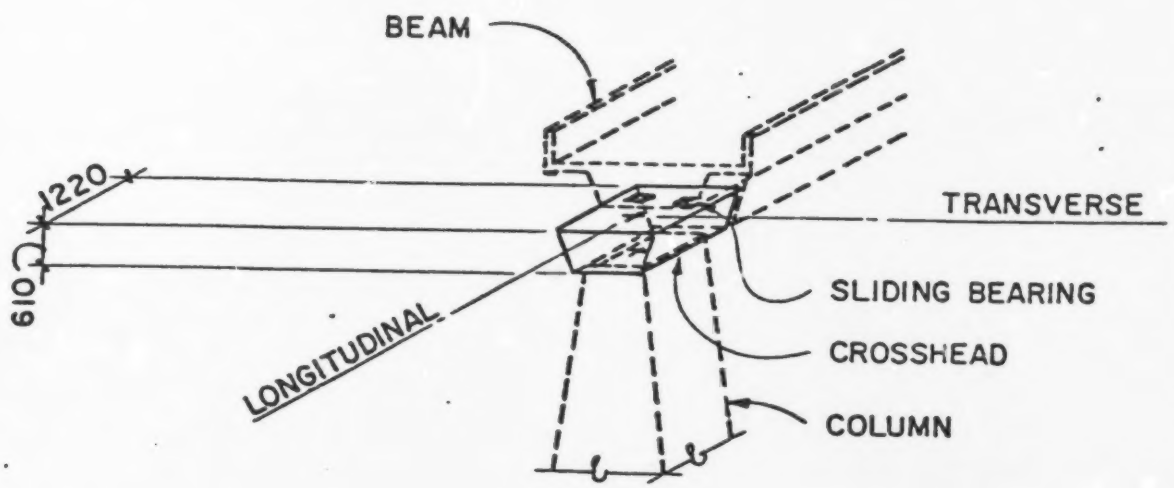


FIGURE 5.1.8

EXPANSION CROSSHEAD

(SINGLE- LANE)

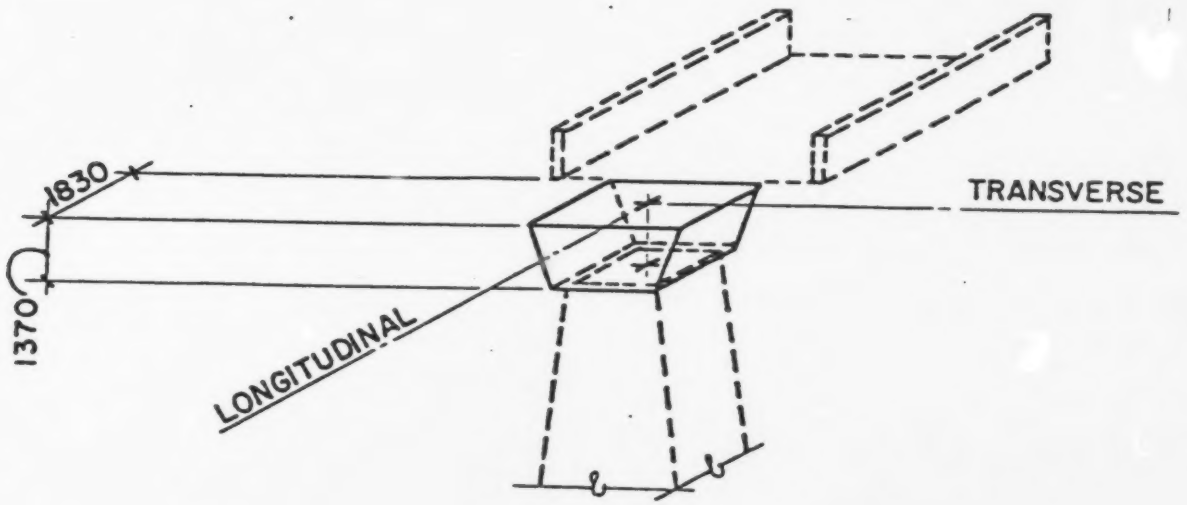
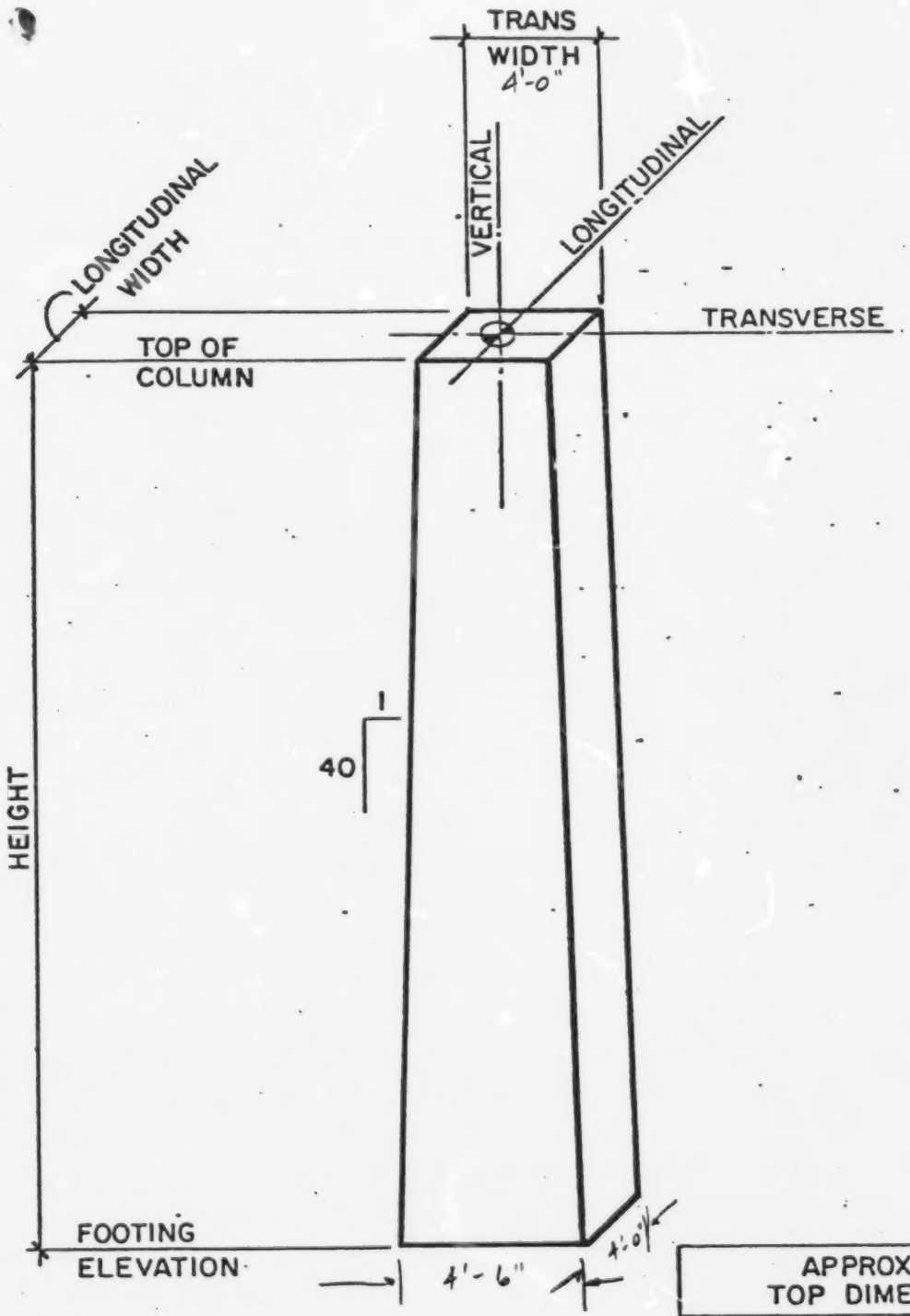


FIGURE 5.1.9

FIXED CROSSHEAD

(SINGLE- LANE)



	APPROXIMATE TOP DIMENSIONS	
	TRANSVERSE	LONGITUDINAL
SINGLE LANE	4'-0" 1220	2'-6" 760
DOUBLE LANE	4'-0" 1220	3'-6" 1070

FIGURE 5.1.10

COLUMN

TYPICAL SYSTEM INTERFACES

The guideway beam cross sections are designed to accommodate the system components:

trackwork

LIM (linear induction motor) rail

power rail and

CCC (command, control and communications) cable

as shown in Figure 5.1.11.

Trackwork

Trackwork consists of running rail and rail fasteners in typical guideway sections and of special hardware (switches, frogs, expansion joints, switch actuation machines and attachments) in crossover areas. All trackwork is attached directly to the concrete deck surface with specialized fastening systems. Since the trackwork directly supports the vehicle, system components are toleranced from the top of the running rails.

Linear Induction Motor (LIM)

The LIM is used for the ICTS Propulsion system to provide rapid smooth longitudinal acceleration and deceleration. This allows for closer vehicle headways. Use of the LIM also removes the primary braking mode of the vehicle from the wheel/rail contact surface. This allows the vehicle to operate in a harsh snow and ice environment.

The LIM consists of the LIM primary rigidly fixed to the axles of the vehicle (two per vehicle) and the LIM secondary attached to the guideway. The LIM secondary consists of an aluminum top cap placed over a steel core. Two configurations of this steel core are used, a laminated back iron and a solid back iron. The laminated back iron is more costly and is used in areas where higher performance is desired.

Solid-state converters (one per LIM) control power flow and convert the direct current to variable voltage, variable frequency alternating current. During deacceleration the converters return direct-current power to the system.

Power Rail

The power rails are mounted on the side of the guideway. The power rails feed the vehicle LIM motors through a two-rail, 600 v direct current system. Sets of carbon collector shoes are mounted on both sides of the vehicle.

Shroud?

Command, Control, Communication (CCC)

The CCC inductive loop, located just below and inside of the rail head, transmits instructions from the control center to the vehicle.

Vehicle control is based on the moving block system and consists of the following subsystems. The System Management Center is a single processor which, in conjunction with a human operator carries out all supervisory functions. The Vehicle Control Center is a triple-redundant processor with responsibility for safe train movement. The Vehicle-on-Board Control is a redundant processor which receives and verifies commands from Vehicle Control Center and executes the given commands. Three types of control systems are available - automatic (as described above) cab-signalling, and manual.

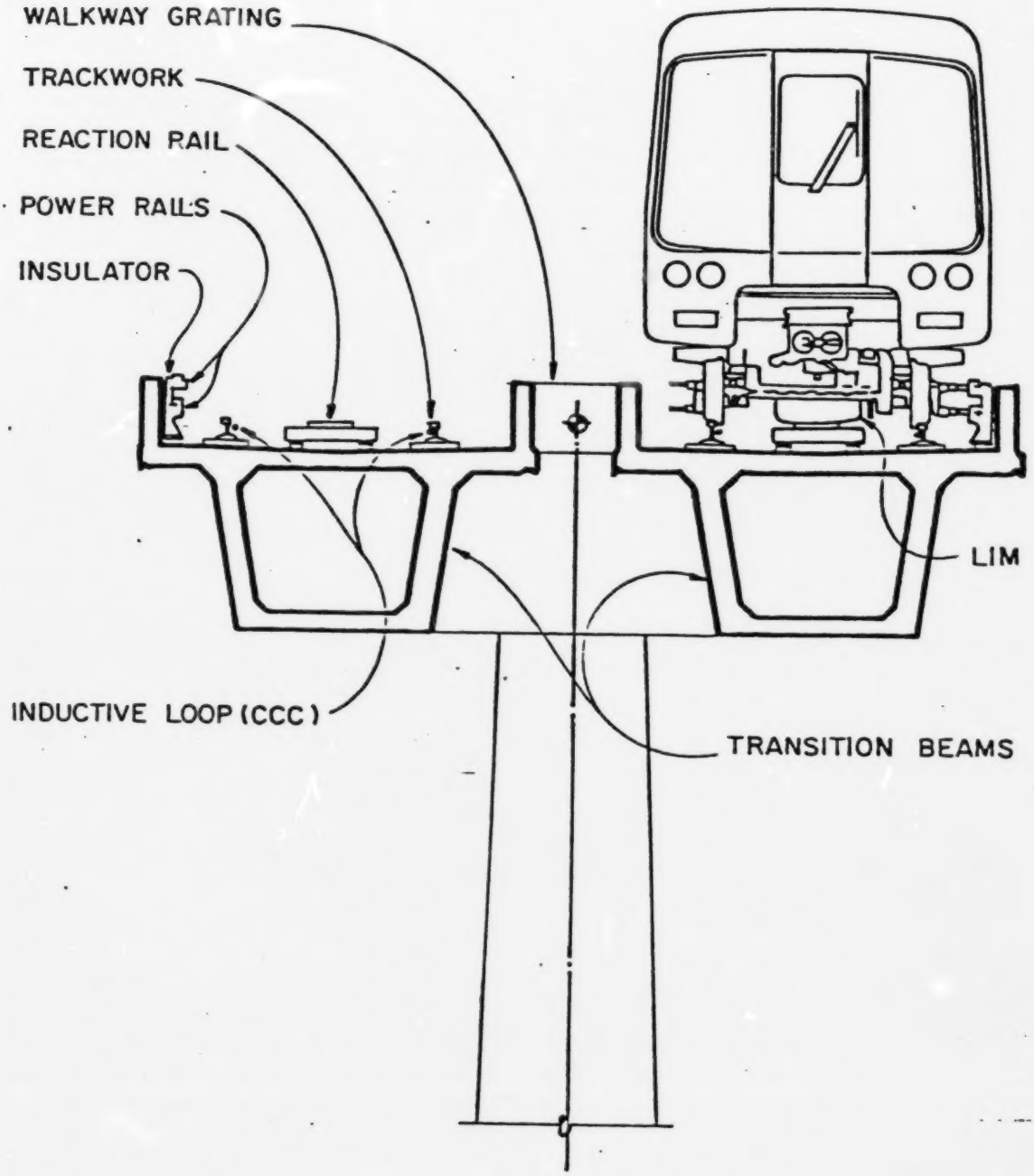


FIGURE 5.1.11

SYSTEM INTERFACES

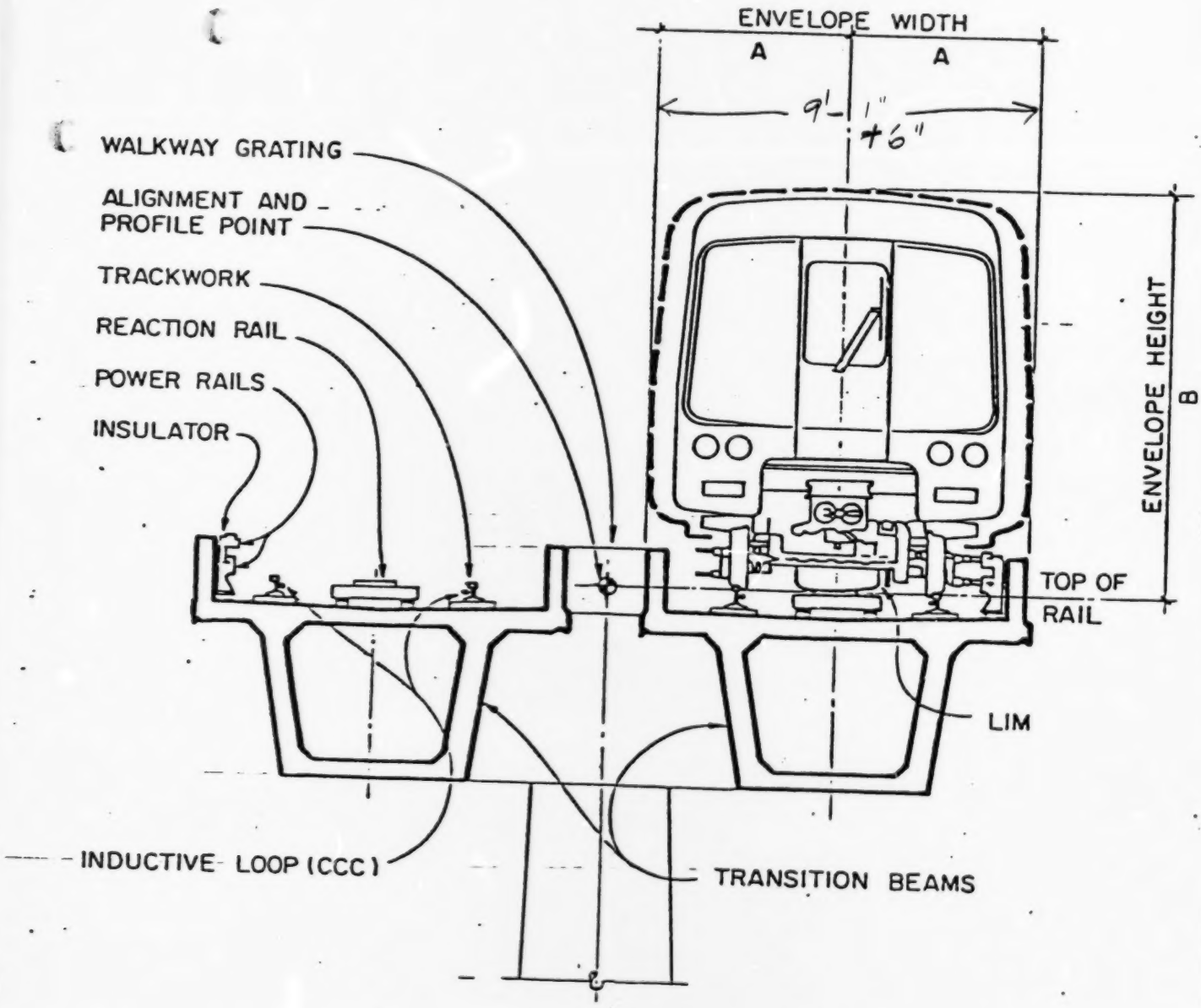
DYNAMIC ENVELOPE

The dynamic envelope is the space above the guideway required for safe passage of the vehicle. For normal service conditions the dynamic envelope width/height is determined by:

- nominal vehicle width/height
- wheelset movement
- flange wear
- rail wear
- carbody truck motion

In a degraded condition the vehicle suspension system is assumed to fail. Additional width is then required to move the vehicle along the guideway back to the maintenance area.

The dynamic envelope parameters are summarized in the Figure 5.1.12. The dynamic envelope does not include a safety margin, therefore a minimum 150 mm clearance envelope should be added for clearing utilities, buildings, and other fixed structures along the route. Additional clearance should be provided if adjacent structures or objects have expansion possibilities or dynamic characteristics, e.g., power wires. A minimum of 100 mm is required between the dynamic envelopes of passing vehicles.



CURVE RADIUS	NORMAL CONDITION		DEGRADED CONDITION	
	A	B	A	B
TANGENT	1311	3185	1368	3185
150 m	1375	3185	1432	3185
35m	1576	3185	1633	3185 (10'-5") +6"

FIGURE 5.1.12

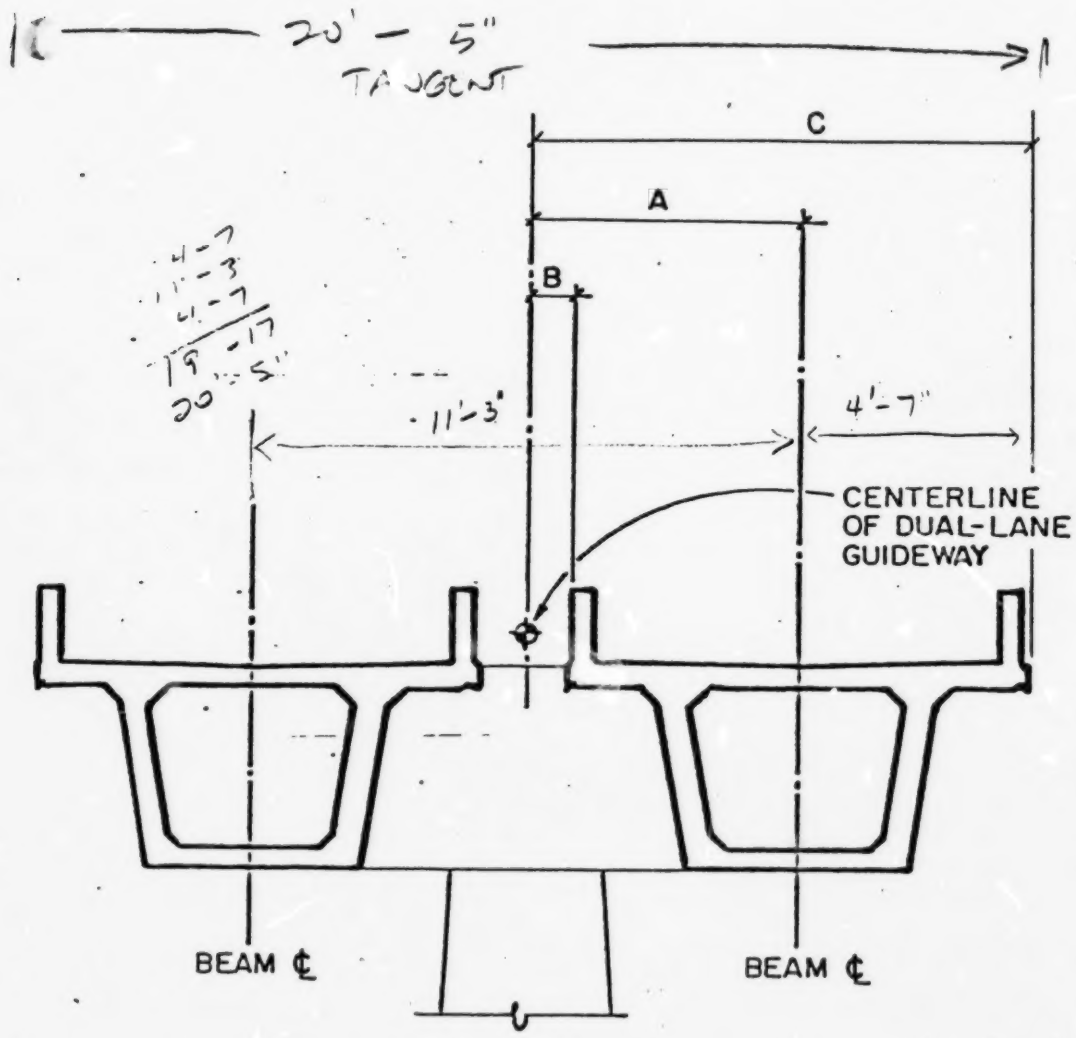
DYNAMIC ENVELOPE

DUAL-LANE GUIDEWAY SEPARATION

The dual-line guideway separations are presented in figure 5.1.13 for varying curve radii and are determined by three factors:

1. Vehicle dynamic envelopes for normal conditions,
2. A minimum walkway width of 610 mm and 2'-0"
3. A 100 mm safety margin between the walkway and vehicle dynamic envelopes.

NOTE: A minimum separation of 3435 mm between guideway beam centerlines was set by Metro Canada Ltd., (Kingston) and is the basis for standard crossover geometry.



SEPARATION FROM CENTERLINE			
RADIUS (m)	A (m)	B (m)	C (m)
TANGENT	1717.5	340.5	3114.5
600	1733	356	3130
300	1748	371	3145
150	1779	402	3176
75	1841	464	3238
50	1902	525	3299
35	1982	605	3379

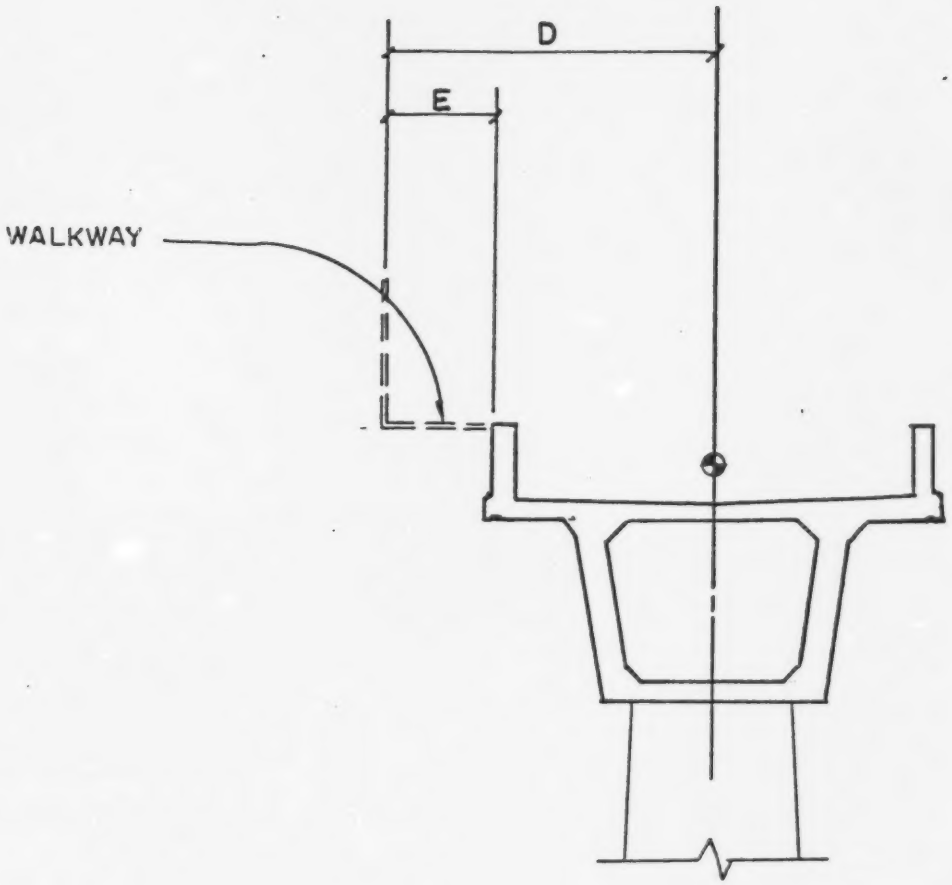
FIGURE 5.1.13

DUAL-LANE GUIDEWAY SEPARATION

SINGLE-LANE GUIDEWAY EXTENSION

A space allowance must be made for the walkway extending out from single-lane guideways. The extension dimensions are presented in figure 5.1.14 for varying curve radii and are determined by four factors:

1. Vehicle dynamic envelope for normal conditions,
2. A minimum walkway width of 610 mm,
3. A 100 mm safety margin between the walkway and vehicle dynamic envelopes and,
4. A 50 mm allowance for the safety railing.



EXTENSION FROM CENTERLINE		
RADIUS (m)	D (m)	E (m)
TANGENT	2071	694
600	2087	710
300	2102	725
150	2133	756
75	2195	818
50	2256	879
35	2336	959

FIGURE 5.1.14

SINGLE-LANE GUIDEWAY EXTENSION

STATION PLATFORMS

Stations are structurally independent of the guideway; however the guideway structure and system operations determine specific parameters which need to be considered in station design and platform location. Parameters include:

Platform length (4 car train)	55 m (180')
Platform elevation	760 mm (above top of rail)
Platform to vehicle gap	65 mm
Maximum grade at stations	0.5%

Refer to figure 5.1.15

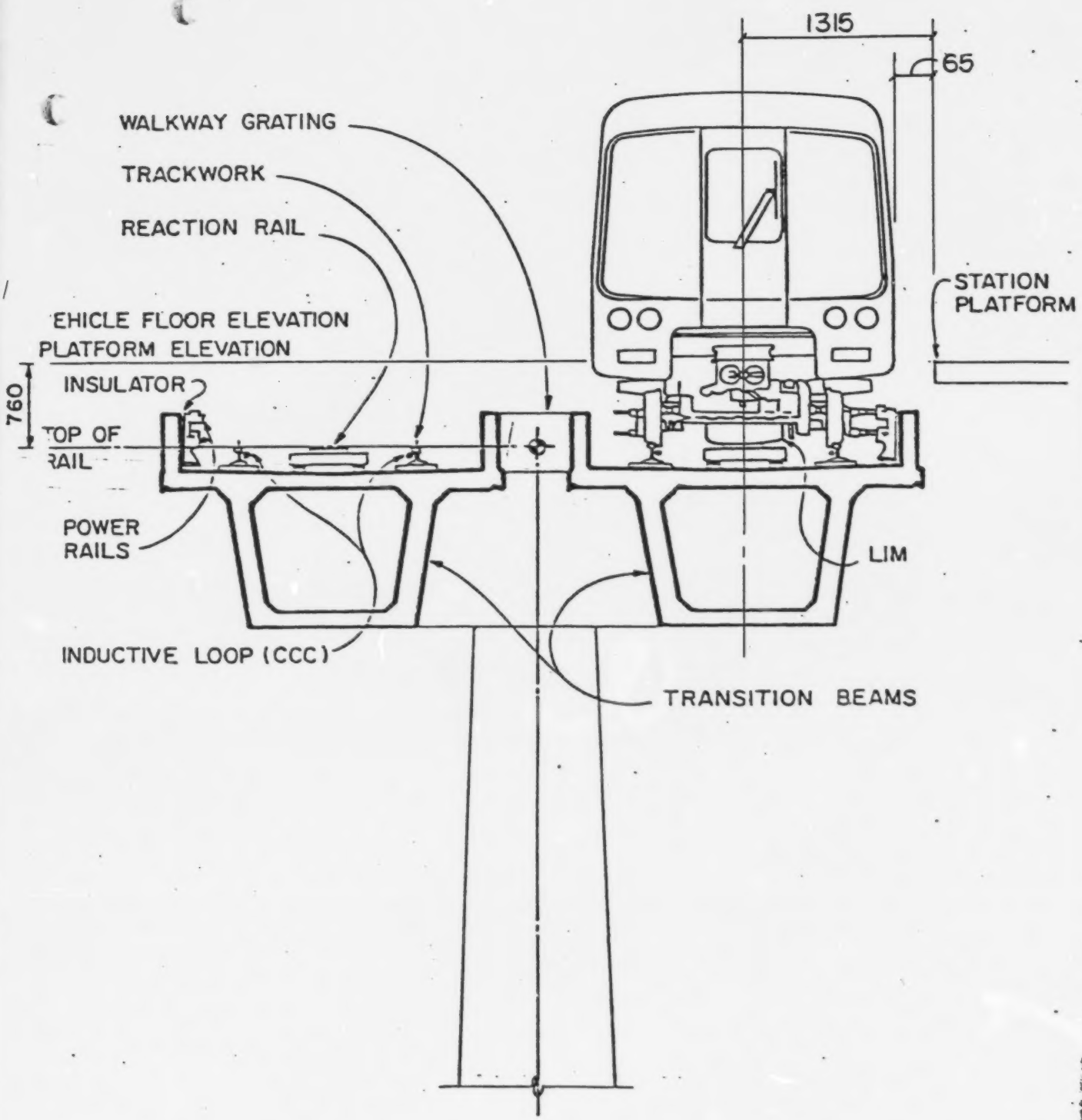


FIGURE 5.1.15

STATION PLATFORM LOCATION

5.2 OPERATIONAL REQUIREMENTS

INTRODUCTION

The Operational Requirements address the internal and external factors which impact the guideway design. These requirements address environmental conditions, system performance, vehicle operations, speed vs. horizontal curvature and walkways.

Environmental conditions describe wind, rain, snow, ice and temperature conditions. These conditions affect the size of appurtenances and loads on the structure.

System performance information contain a summary of operational characteristics of ICTS. The data is provided to complete the description of external factors influencing the transit system operation. Some operation considerations, such as the possibility of four car trains, impact the guideway design.

Vehicle operations provide the dynamic conditions on the vehicle which result in direct forces on the guideway. Operating conditions result in lateral and longitudinal loading combinations. The speed vs. curve information relates some of these operation conditions to physical layout considerations.

The walkway data interprets the operation requirements and emergency egress requirements of the system. A minimum impact walkway is presented.

ENVIRONMENTAL CONDITIONS

Site independent system environmental factors are given in Table 5.2.1. The values for wind velocity at which vehicles are removed, the operating rainfall intensity, the operating snowfall intensity, and the operating ice accumulation are shown. Site dependent parameters are given in Table 5.2.2.

ENVIRONMENTAL CONDITION	SI UNITS	IMPERIAL UNITS
Wind velocity (steady-state) at which vehicles are removed from the guideway	24 m/s	54 mph
Maximum Operating Rainfall Intensity	6.6 cm/h 12 cm/day	2.6 in/hr 4.8 in/day
Maximum Operating Snowfall Intensity	4.4 cm/hr 53 cm/day	1.75 in/hr 21 in/day
Operating Ice Accumulation on Horizontal and Vertical Surfaces	0.75 cm/hr 1.5 cm/day	0.3 in/hr 0.6 in/day

TABLE 5.2.1 ICTS GUIDEWAY SITE DEPENDENT DESIGN ENVIRONMENTAL CONDITIONS

ENVIRONMENTAL CONDITION	SI UNITS	IMPERIAL UNITS
Seismic Zone	2	2
Maximum Wind Velocity (steady-state) on guideway only	31 m/s	70 mph
Ambient Temp. Range - Min - Max	$-40^{o}C$ $43^{o}C$	$-40^{o}F$ $100^{o}F$
Structure Temp. Range - Rise - Fall	$30^{o}C$ $39^{o}C$	$55^{o}F$ $70^{o}F$
Maximum Railfall Intensity (non-operational)	9.6 cm/hr	3.8 in/hr
Maximum Snowfall (non-operational)	62 cm	24.5 in
Maximum Ice Accumulation on Horizontal & Vertical Surfaces (non-operation)	4.0 cm	1.6 in

TABLE 5.2.2 ICTS GUIDEWAY SITE DEPENDENT DESIGN ENVIRONMENTAL CONIDTIONS

The guideway shall include adequate provisions for draining moisture from the guideway surfaces. This drainage shall have the capacity to route water to established storm sewers, limiting the quantity falling from the structure to sidewalks and streets below. Joint and interface detials shall be designed with waterstops, drip strips and other applicable features to maximize drip protection of the elevated guideway. Refer to Figure 5.2.1.

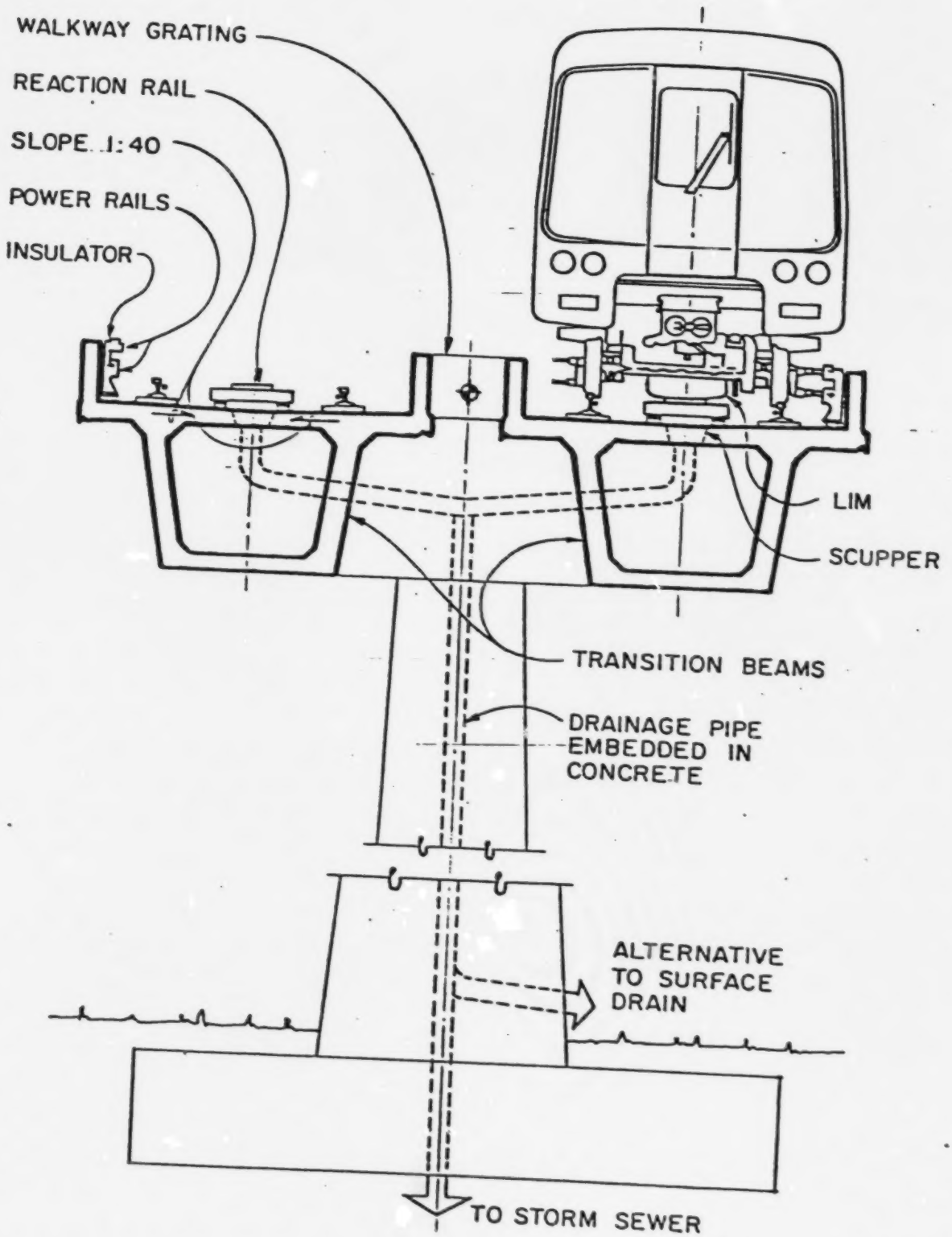


FIGURE 5.2.1

DRAINAGE

SYSTEM PERFORMANCE:

Performance Characteristics for a four-vehicle train	
Max. Theoretical Sgl. Direction Cap.	25,400 pax/h
Max. Practical Sgl. Direction Cap.	19,900 pax/h
Min. Theoretical Headway	47 sec
Min. Practical Headway	60 sec
Operating Modes	Scheduled
Type of Vehicle Routing	Variable
Traveling Unit	Up to 4 vehicle trains

VEHICLE:

Suspension Type	Steel wheels, 2 radial trucks per vehicle, 2 axles per truck as primary suspension; rolling sleeve airbag or rubber springs as secondary suspension.
Lateral Guidance	Coned, flanged steel wheels
Comfort	Enclosed vehicle, heated, air-conditioned and ventilated
Security	Two-way communication with central control
Overall Length (per mid-size car)	12,700 mm
Overall Width	2,500 mm
Overall Height	3,125 mm
Empty Weight	13,000 kg
Stopping Precision in Station	150 mm
One or Bi-Directional	Bi-Directional
Noise	66 dBA inside vehicle
Noise	67 dBA at 15 m from centerline of guideway
Total Pax Area (Centre Car)	24.9 m^2
Total Pax Area (End Car)	23.2 m^2
Floor Area for Seated Pax	12.0 m^2
Floor Area for Standing Pax	11.25 m^2
Vehicle Design Capacity	28 seated; 55 standing
Vehicle Crush Capacity	28 seated; 77 standing
Doorway Width	1,220 mm
Doorway Height	1,930 mm
No. of Doors per Vehicle	2 left side; 2 right side

PROPULSION:

2 linear induction motors (LIM) per vehicle	
Motor Rating	130 kw
Type Power	600 vdc
Power Collection	Truck-mounted side pick-up; two sets of shoes per truck
Propulsion Input Power	Variable frequency and voltage 3 phase AC
Vehicle Auxiliary System Input Power	37.5 VDC
Type Service Brakes	LIM in regenerative or dynamic mode. Disc brakes (pneumatic and hydraulic options) used for parking only in service mode.
Type Emergency Brakes	Electromagnetic track brakes assisted with disc brakes

SWITCHING:

Type and Emplacement	Track-based switching; movable frog or fixed frog
Switch Time (Lock-to-Lock)	3 seconds
Max. Speed Through Switch	72 km/h
Min. Headway Through Switch	60 seconds

STATIONS:

Type	On-line or Off-line
Type Boarding	Level
Minimum Vehicle Station Dwell Time	5 sec

VEHICLE OPERATIONS:

The vehicle operational constraints prescribed in the ICTS Contract General Model Specifications are given below. The guideway geometrics satisfying these constraints are presented in a later section.

	SI UNITS	IMPERIAL UNITS
Maximum Velocity	21.5 m/s	70.54 ft/s
Operating Velocity	20.0 m/s	65.62 ft/s
Maximum Sustained Lateral Acceleration on Passengers	.10 g	
Maximum Sustained Longitudinal Acceleration on Passengers	.13 g	
Emergency Longitudinal Acceleration on Passengers	.30 g	
Maximum Sustained Lateral Jerk on Passengers	.05 g/s	
Maximum Sustained Longitudinal Jerk on Passengers	.10 g/s	
Maximum Superelevation	10%	
Maximum Rate of Change of Superelevation	.25%/m	.076%/ft
or	.035 m/s	.115 ft/s
Maximum Sustained Grade - Nominal Operation	10%	
Minimum Sustained Grade	0.5%	
Maximum Sustained Vertical Acceleration on Passengers	0.10g	
Maximum Sustained Vertical Jerk on Passengers	0.05g/s	

WALKWAY

The walkway functions both as an emergency egress for passengers and also as a platform for maintenance personnel. It is located between beams of dual-lane guideways (figure 5.2.2). On single-lane guideways the walkway is on the side of the beam (figure 5.2.3). The minimum walkway width is 610 mm. It should be noted that the Hamilton Rapid Transit walkway, permitting emergency egress from the side doors of the vehicle, does not conform to the present ICTS system solution which assumes that emergency egress is through the vehicle end doors only.

It is recommended that the walkway be level with the top of the guideway sidewalls. This locates the walkway:

395 mm below the vehicle floor, 16"
365 mm above the top of the rails and
565 mm above the guideway deck. 22"

A railing is required for safety on the outside of single-lane walkways. The height as required by the Ontario Building Code is 1067 mm (42 inches).

Since all guideways are required to maintain a minimum 0.5% slope for drainage, it appears unreasonable to step the walkway for the entire length of the system. It is recommended that steps of 100 mm rise be used on guideway grades greater than 4%.

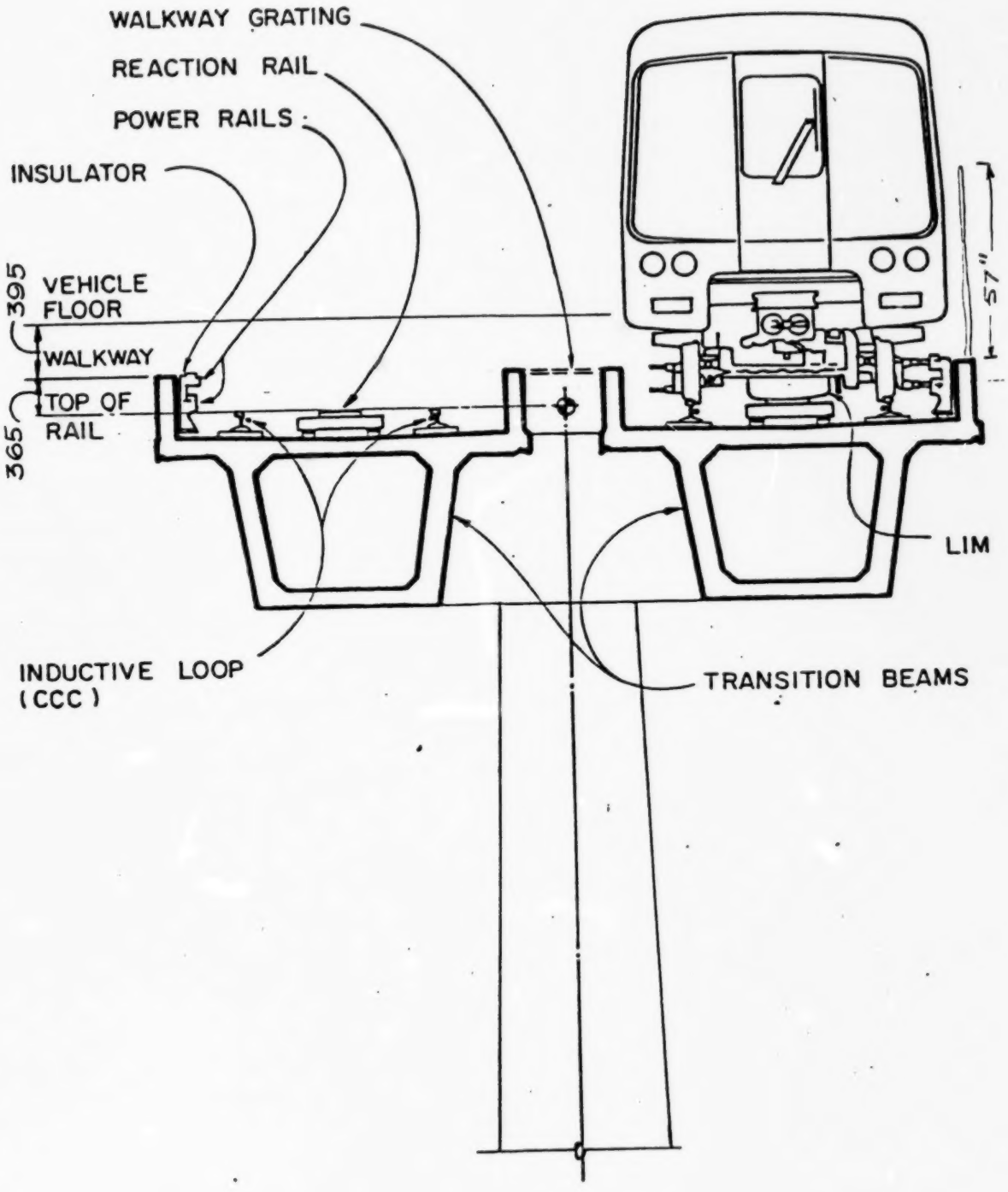


FIGURE 5.2.2

WALKWAY

(DUAL- LANE)

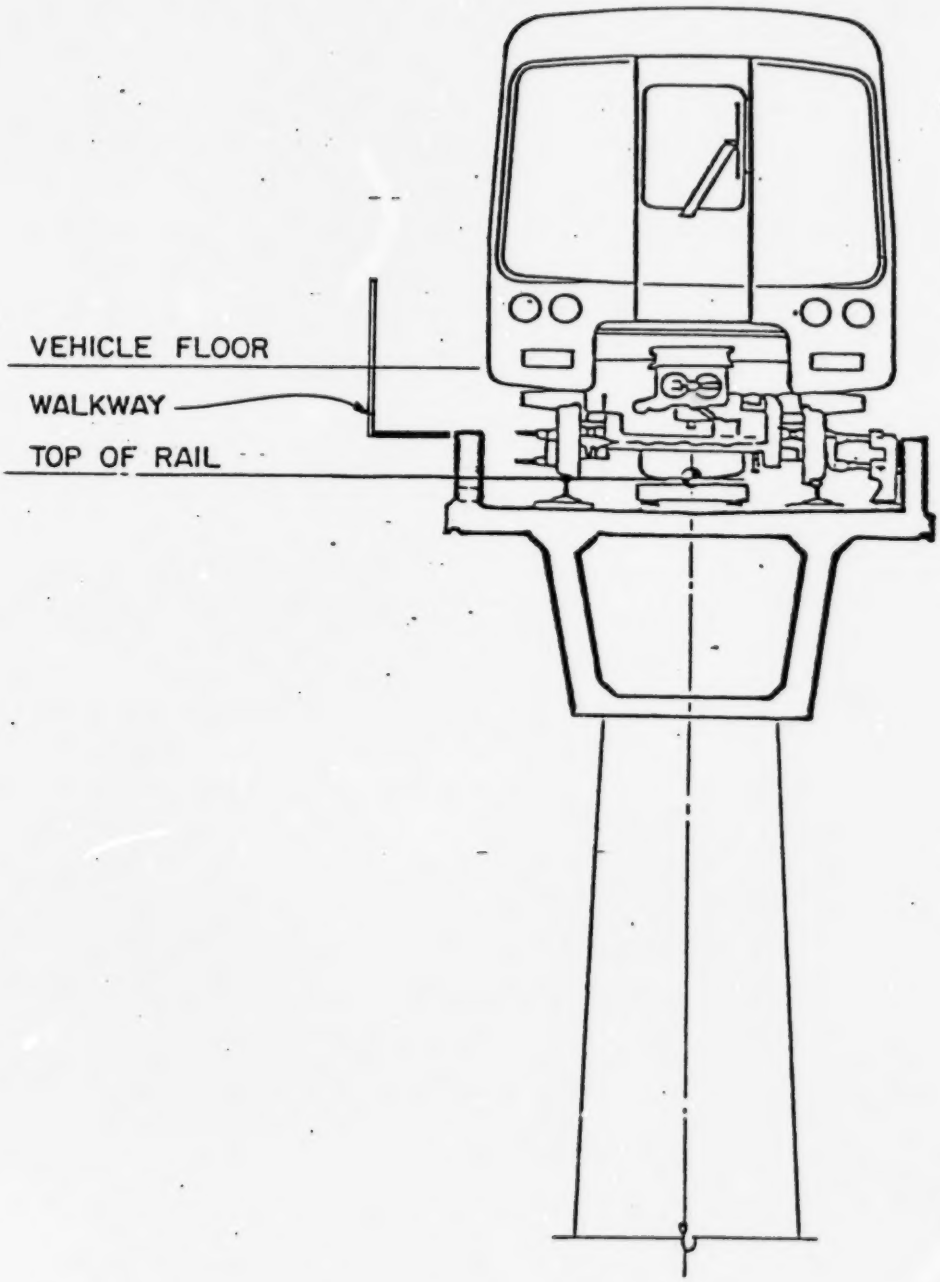


FIGURE 5.2.3

WALKWAY

(SINGLE - LANE)

SPEED CURVE DATA

The speed of a vehicle is related to the curve radius by ride comfort criteria. Allowable speeds can be increased in curves by superelevating the beams. Refer to Table 5.2.3.

Design and construction are simplified when superelevation is zero; and correspondingly guideway costs are reduced.

However, one must consider the effects of zero superelevation on the system. As compared to superelevated curves, zero superelevation lowers:

1) allowable speeds in the curves
2) average speed
3) circuit time and assuming the same headway
4) system capacity

CURVE RADIUS (m)	SPEED (m/s)	
	With 10% Superelevation	Without Superelevation
35	8.29 /8 mph	5.86 /3 mph
50	9.65 22	7.00
75	11.82 26	8.58
150	16.72 37	12.13
300	20.00 45	17.15
600	20.00 45	20.00

TABLE 5.2.3 SPEED/CURVE TABLE FOR MODULAR CURVES

NOTE: MAXIMUM VELOCITY IS 20 m/s

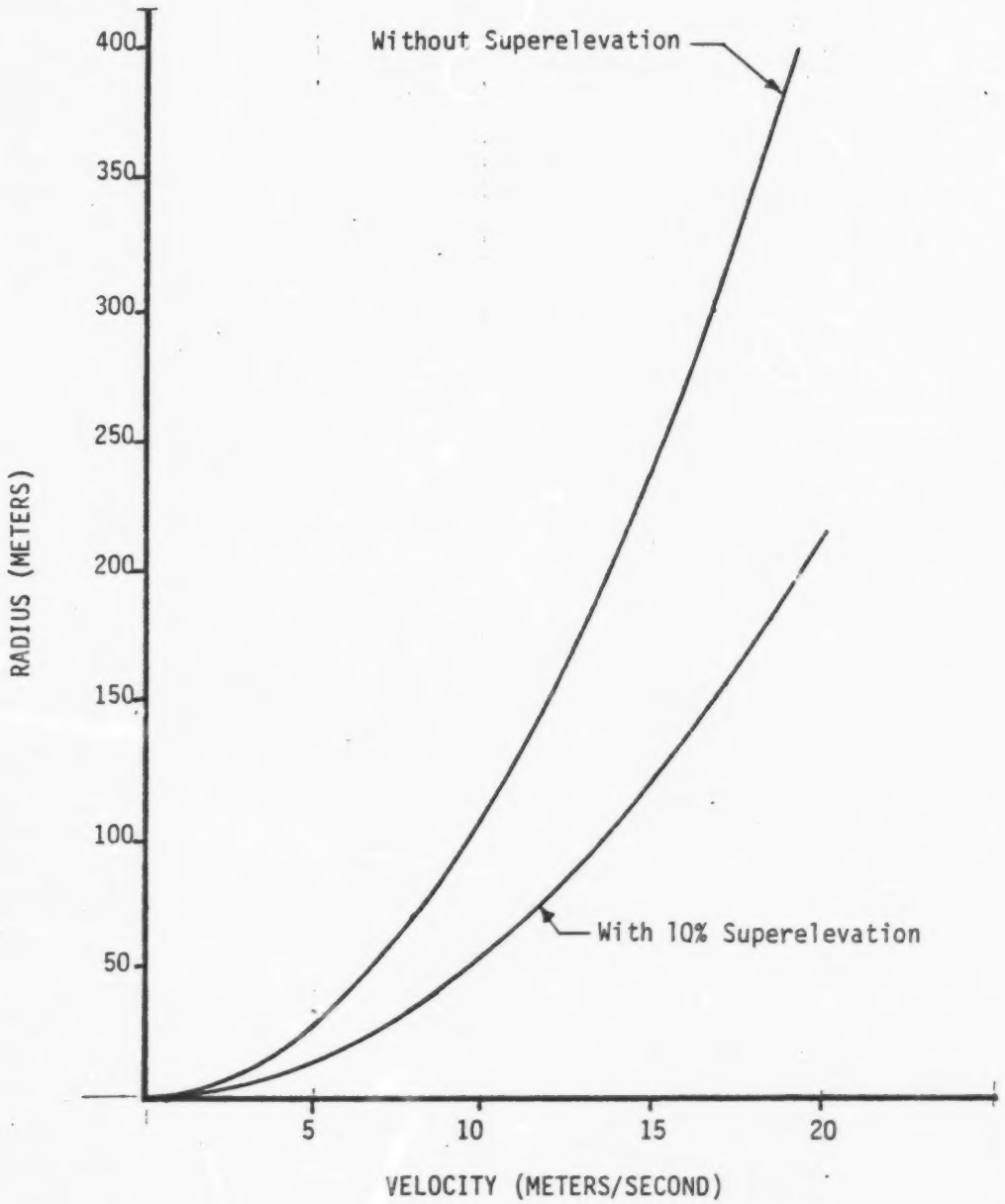


FIGURE 5.2.4 SPEED RADIUS CURVE

5.3 LAYOUT CONSIDERATIONS

INTRODUCTION

Details of the geometric layout can noticeably affect the guideway cost. The guidelines presented in this section are intended to minimize cost without restricting the architectural or performance characteristics of the guideway. Exact details of geometric design are presented in the Geometrics section.

HORIZONTAL CURVES

The horizontal geometry will be laid out with circle curves together with spiral transition curves. Prior to preliminary design it is sufficient to use circle curves only to define the geometrics. These simplifications aid rapid definition of alternative routes but underestimate the total amount of curved guideway and inaccurately place columns. Addition of the spiral transitions is required if close column clearances are being considered.

To minimize the number of various beams which will have to be constructed, designers should attempt to standardize horizontal curvature using the curve radii listed below:

Radius (m)	Superelevation (%)	Spiral Length (m)	Comments
35	0	11.72	Min. allowable rad.
	10	33.97	" " "
50	0	14.00	
	10	40.60	
75	0	17.15	
	10	49.73	
150	0	24.26	
	10	70.33	

Radius (m)	Superelevation (%)	Spiral Length (m)	Comments
300	0	34.31	
	10	82.00	
600	0	48.51	
	10	82.00	

VERTICAL CURVES

The ICTS guideway uses vertical curves with cubic spiral transitions. The spirals and details of the geometry are to assure proper operation of the LIM and to maintain ride quality. The length of the vertical curve also affects the ability to manufacture beam curvature.

Details of the vertical curve geometry are given in the geometrics chapter. For initial layout the following guidelines should apply.

- Curve length ℓ should be greater than 600 times the difference in change in grade g_1 and g_2

$$\ell > 600 (g_1 - g_2)$$

  Comment: This provides a minimum radius of curvature in excess of 600 m. 600 m is usually acceptable within ride comfort criteria and suitable for flexing adjustable beam tooling. g is the ratio: vertical to horizontal dimensions.

- Curve lengths less than one span length should be increased to be an even beam length long or increased to be a multiple of the beam length.

  Comment: Once a beam has vertical curvature, there is little penalty to increasing the amount of the beam that is curved. Some benefit occurs if the curvature is lessened.

- Vertical curves should start and end at columns.

  Comment: This reduces the number of beams with vertical curvature and coordinates the aesthetics of change in grade with discontinuities in the structure.

COLUMN LOCATIONS

Locations of columns are influenced by the location of existing utilities, roads, streets and other physical interferences as well as architectural considerations such as coordination with existing building facades. The following guidelines are presented as methods of maintaining the aesthetic appearance of the completed guideway and of minimizing guideway costs.

- Use the typical beam spans listed below. They are not absolute limits but are currently estimated to be the most cost efficient.

Radius (m)	Dual-Lane (m)	ft	Single-Lane (m)	
tangent	30	98	30	98
600	30	98	30	98
300	28	92	30	98
150	26	85	28	92
75	24	79	26	85
50	22	72	24	79
35	20	66	22	72

Note: For the dual-lane guideway the radius relates to the inside lane but the span is given for the guideway centerline.

- Standardize beam lengths

- Place columns at the natural changes in geometry.
  i.e. curve to spiral point
  spiral to tangent point
  beginning or end of vertical curve

6.0 GEOMETRICS

CENTERLINE DEFINITION

Definition of Horizontal Alignment

The guideway horizontal alignment point is a line at the center of a dual-lane guideway. It is located in a plane created by a line through each of the individual beam centerlines.

The beam centerline is the mid-point of a line between the two rails. The beam centerline is defined by an offset distance measured perpendicular to the guideway centerline.

For single-lane guideway the guideway horizontal alignment and the beam centerline are coincident. Definition of the point of separation between single- and dual-lane guideways is done on a case by case basis. Generally, however, the transition occurs when there is a divergence of geometry or when the capabilities of a single column structure are exceeded.

Figures 5.1.4 and 5.1.5 define both the horizontal and profile alignment.

Definition of Profile Grade Line

The guideway profile grade line is the point on the geometric cross section whose elevation is defined by the horizontal alignment point. This point is shown on preliminary drawings and other documents.

Beamway profile grades are defined as coincident with the beam centerline. These elevations are used on final drawings and are used to establish final station elevations.

Definition of Pivot Point for Superelevated Guideways

The pivot point is the point about which the cross section of the guideway rotates when applying superelevation. The pivot point is usually coincident with the guideway alignment point.

The pivot point is at the centerline of the dual track guideways at an elevation of a line between beam centerlines.

HORIZONTAL CIRCULAR CURVES

In curves of constant radius, lateral acceleration is determined from the expression:

$$a_l = \frac{V^2}{R_h} - g \, (\tan A)$$

The ICTS ride comfort criteria prescribes the following boundary conditions to these acceleration parameters as calculated using the guideway centerline:

a_l (max.) = 0.10 g

Tan A (max.) = 0.00

V (max.) = 20 m/s

R_h (min.) = 35 m

HORIZONTAL SPIRAL CURVES

Cubic spiral curves are used to provide for curvature transitions between tangent and circular curve guideway sections. The cubic spiral is defined by the expression:

$$y = \frac{L_h^3}{6R_{ch}\ L_{sh}}$$

ICTS ride comfort criteria limits the lateral jerk rate in a spiral to 0.05 g/s. The lateral jerk rate is determined by the expression:

$$J_l = \frac{V^3}{gR_{ch}\ L_{sh}} - \frac{V\ (\tan A)}{L_{sh}}$$

SUPERELEVATION

Superelevation is the rotation of the guideway in curves to counterbalance the lateral acceleration felt by passengers. The guideway rotates about a pivot point, located at the guideway centerline. Ride comfort criteria limits superelevation to (tan A) = 0.10.

In curves superelevation is constant but in spirals it transitions linearly from tan A = 0 to tan A = 0.10. The rate of superelevation is limited to 0.035 m/s, and therefore determines a minimum spiral length.

$$Ls_1 = \frac{V\, g_r\, (\tan A)}{0.035}$$

where:

g_r = 1.435 m (rail gage)

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VERTICAL CIRCULAR CURVES

Vertical geometrics are similar to horizontal geometrics except superelevation does not apply; therefore vertical acceleration in vertical constant radius curves is determined from the expression:

$$A_v = \frac{V^2}{R_v}$$

The following boundary conditions apply to these acceleration parameters as calculated using the guideway centerline.

A_v (max.) = 0.10 g

V (max.) = 20 m/s

R_v (min.) = 600 m

VERTICAL SPIRAL CURVES

Cubic spiral curves are used to provide vertical curvature transitions also. The cubic spiral is defined by the expression:

$$z = \frac{LV^3}{6R_{cv}\, L_{sv}}$$

ICTS ride comfort criteria limits the vertical jerk rate in a spiral to 0.05 g/s. The vertical jerk rate is determined by the expression:

$$J_v = \frac{V^3}{gR_{cv}\, L_{sv}} - \frac{V\,(\tan A)}{L_{sv}}$$

7.0 STRUCTURAL

INTRODUCTION

The structural guidelines present a summary of all guideway loads and design guidelines for final guideway deisgn and a listing of codes and other reference sources.

The load summary recaps the internal and external loads on the guideway. Vehicle specific loads, centrifugal force for example, use the vehicle sizes and weights presented in the General Requirements.

Design Guidelines are a composite of relevant codes and rational data obtained from design and testing at the Kingston Site Testing Facility. Criteria address service life, service loads, strength design and fatigue.

Codes and References present several relevant design documents which supplement the detailed design criteria. These references frequently contain the commentary describing the development of the specific recommendation in the Design Guidelines.

LOADS SUMMARY

Below is a summary of loads and their values to be applied to "Service Load Design."

D = Dead Load, all structure and equipment which is permanently fastened to the guideway. A summary of design values is given in Table 7.1

	kN/m	kip/ft
Basic Beamway	25.67	1.77
Side Walls	3.91	0.27
Noise Walls	Not included in Basic Design	
Power Rails	0.36	0.03
LIM Secondary and Attachments	1.09	0.08
ATC Loop	0	0
Running Rails and Attachments (115# REA)	1.60	0.11
Conduits & Miscellaneous	0.29	0.02
Walkways	Undefined	

TABLE 7.1 DEAD LOAD VALUES

L = Vertical live load exerted by a train consist of one to four loaded vehicles on one or both lanes of the dual guideway. Each crush vehicle load is 21,160 kg, not including snow and ice (SIV).

I = Vertical impact associated with live load under consideration which may or may not include snow and ice (SW).

$I = 0.10\ L + .10\ SIV$ or $0.10\ L$

In switch areas and for structural components over sliding expansion joints in the rail.

$I = 0.30\ L + 0.30\ SIV$ or $0.30\ L$

Lurching Load: The design lurching load applied to the structure is the torque associated with an unbalance in wheel load. The unbalance ranges from 84% to 116% of the normal wheel load.

Centrifugal Force (CF, CF2)
CF = Normal Centrifugal Force

$= (\frac{V2}{Rg} - e)\ L$ on beams

$= (\frac{V2}{Rg})\ L$ on columns

applied at the vehicle center of gravity, where

V = Vehicle velocity; the design velocity shall be the design velocity permitted on the guideway structure to keep the lateral accelerations within the ride comfort criteria plus the incremental velocity allowed by the vehicle speed control system.

R = Radius

g = Acceleration due to gravity

L = Vehicle live load (may or may not include snow and ice)

e = Superelevation

TABLE OF CENTRIFUGAL FORCE

R m (ft)	e	V_{des} m/s (ft/s)	$V = V_{des} + V_{over\ speed}$ m/s (ft/s)	Horizontal Acceleration -g-
150 (492)	0.10	17.15 (56.3)	18.65 (61.2)	.237
35 (115)	0	5.86 (19.2)	6.86 (22.5)	.137

V_{des}	$V_{over\ speed}$
0 - 3.8 m/s	0.50 m/s
3.8 - 14.0 m/s	1.00 m/s
14.0 - 20.0 m/s	1.50 m/s

CF2 = Extreme Centrifugal Force:

R m (ft)	e	V_{max} m/s (ft/s)	Equivalent Horizontal Acceleration on Crush-Loaded Vehicle -g-
150 (492)	0.10	24.0 (78.7)	0.252
35 (115)	0	16.9 (55.4)	0.534

V_{max} is computed on a velocity which causes tipping of an empty vehicle or a 24 m/s on an empty vehicle whichever is less.

HF = Steering and Hunting Forces:

$$\frac{HF}{2/8\ (L + SIV)} = 1.0$$

HF = 51.9 kN (11.7^K) for two axles of one vehicle (SIV = 0)

HF = 56.3 kN (12.7^K) for two axles of one vehicle (SIV = as given below).

LN = Normal Longitudinal Braking or Acceleration Force:

LN = 0.13 (L) = 27.0 kN (6.1^K) per vehicle, SIV = 0.

LN = 0.13 (L + SIV) = 29.3 kN (6.6^K) per vehicle, SIV = as given below.

LE = Emergency Longitudinal Braking Force:

LE = A maximum of 46.0 kN (10.34^K) per rail per vehicle.

$COLH_H$ and $COLF_V$ = Horizontal and Vertical Vehicle Collision Loads:

$COLH_H$ = 2 - 74.3 kN (16.7^K) concentrated horizontal loads.

$COLF_V$ = 86.0 kN-m (63.4 k-ft) concentrated torque.

The plastic moment strength of the sidewall limits the horizontal force applied to the guideway structures to 16.7^K during a vehicle collision. These forces are predicted on using a sidewall 150 mm (6 in) thick with vertical reinforcing of No. 5 bars at 150 mm (6 in) on center centered in the wall section.

W_1 = Wind pressure at which vehicles are removed from the guideway. Mean wind velocity = 24 m/s (54 mph).

W_2 = Maximum wind pressure on structure only. Mean wind velocity = 31 m/s (70 mph).

Condition	Vehicle	Structure Lateral	Structure Vertical
W_1 Single Lane	1.16 kpa 24.3 psf	1.16 kpa 32.7 psf	0.78 kpa 16.4 psf
W_1 Dual Lane	1.39 kpa 29.2 psf	1.87 kpa 39.2 psf	0.78 19.6 psf
W_2 Single Lane		2.62 kpa 55.0 psf	1.31 kpa 27.5 psf
W_2 Dual Lane		3.14 kpa 66.0 psf	1.57 kpa 33.0 psf

All values are based on Ce = 1.1

EQ = Earthquake Loads

T = Thermal Effect

SIV = Ice Load Attached to the Vehicle (Normal Operations) 17.66 kN (4.0^k) per vehicle

SIG = Snow and Ice Load on the Guideway (Normal Operations)

SIG = 1150 Pa (24.1 psf) for 115 lb REA rail

R = Effect of Rib-shortening due to prestressing

S = Effect of Concrete Shrinkage

ST = Accidental Load due to collision of street traffic = 1000 kN (2.25^k load applied to columns at a height of 1 m (3 ft) above ground level.

LR_1 = Longitudinal Restraint force (Normal Operations) LR_1 = TBD

LR_2 = Longitudinal Restraint Force (Malfunction Condition) LR_2 = TBD

BR = Broken Rail Force. The forces are derived from considerations of interaction of the structure and trackwork.

RT = Radial Thermal Forces. These forces are a function of radius of curve, rail size and temperature drop with respect to rail setting temperature.

CODES AND REFERENCES

Related Transit Codes:

Relevant portions of the following transit codes and criteria have been given close consideration in the formulation of the Design Criteria and Commentary for the ICTS guideway structure:

1) AASHTO — Standard Specifications for Highway Bridges, 1977. (American Association of State Highway and Transportation Officials.)

2) MTC — Ontario Highway Bridge Design Code, 1979. Ministry of Transportation and Communications.

3) CSA-S6 — Design of Highway Bridge (Canadian Standards Association), 1974.

4) AREA — Railway Design Code (American Railway Engineering Association), 1973.

5) CSA-S1 — Steel Railway Bridge (Canadian Standards Association), 1966.

6) ACI 443 — Analyses and Design of Reinforced Concrete Bridge Structures, 1977.

7) BS-116 — British Standards Institute Technical Committee, Steel and Concrete Bridges (Draft), 1976.

8) BART — Bay Area Rapid Transit Design Criteria, 1963.

9) MARTA — Metropolitan Atlanta Rapid Transit Authority Design Criteria, 1974.

10) WMATA Washington Metropolitan Area Transit Authority Design Criteria, 1967.

11) Detroit Downtown People Mover Performance Specifications, 1980.

12) Los Angeles Downtown People Mover System Specifications, April 1980.

13) Miami Downtown People Mover System Specifications, August 1980.

14) CALTRANS California Department of Transportation, Bridge Planning and Design Manual, April 1977, Section 2-16, Seismic Forces.

Criteria for the elevated portion of guideway are based primarily on the ACI Committee 443 report (Reference 6). This report is the most current data available that addresses fatigue and serviceability for repeated loads. ACI Committee 443 is the bridge code equivalent of Committee 318 for building codes.

Criteria for the at-grade portion of the guideway are based primarily on the U.S. Steel "Design Manual for Continuously Reinforced Concrete Pavement" (Reference 27), as listed in the following section. It also draws from past experience in the design and construction of at-grade systems, since the design effort demands a much more empirical approach than that for elevated systems. This is due to the heavy emphasis on soil/ structure interaction.

Reference Documents:

Other codes, recommendations and papers have been instrumental in the development of this Design Criteria and Commentary:

15) "Review of Guideway Design Criteria in Existing Transit System Codes," R.A. Dorton, and H. Grouni, Ontario Ministry of Transportation and Communications, November 1975.

16) Canadian National Building Code (NBC).

17) Climatic Information for Building Design in Canada, Supplement No. 1 to NBC, 1975.

18) Wind Forces on Structures. (A compilation of six papers presented in the July 1958 ASCE Journal of the Structural Division.)

19) Building Code Requirements for Reinforced Concrete (ACI 318-77).

20) Code for the Design of Concrete Structures for Buildings (CSA-A23.3).

21) Concrete Materials and Methods of Concrete Construction (CSA-A23.1).

22) Manual of Quality Control (PCI Manual 116).

23) Billet-Steel Bars for Concrete Reinforcement (CSA-G30.5).

24) Welded Steel Wire Fabric for Concrete Reinforcement (CSA-G30.5).

25) Tentative Recommendations for Prestressed Concrete, (ACI-ASCE Joint Committee 423).

26) The Ontario Ministry of Transportation and Communications. General Conditions and Standard Specifications (Volumes 1 and 2).

27) Design Manual for Continuously Reinforced Concrete Pavement (United States Steel Corporation), 1970.

28) National Building Code of Canada, Supplement No. 4 Canadian Structural Design Manual, 1970.

29) "Recommended Lateral Force Requirements and Commentary," Seismology Committee, Structural Engineers Association of California, 1975.

30) "The Steady-State Aerodynamics of Elevated Rectangular Transit Vehicles," Teunissen and Cooper, Laboratory Technical Report No. LTR-LA-179, National Research Council of Canada, 1975.

31) "Thermal Expansion of Concrete and Reinforced Concrete," Berwanger and Sarkar, Journal of the American Concrete Institute, November 1976.

32) Seismic Design of Highway Bridges, Workshop Manual, February 5-9, 1979, Olympia, Washington. Sponsored by USDOT (FHA) and given by Engineering Computer Corporation (ECC), Sacramento, California.

33) Rational for Determining Design Wind Velocities, A.G. Davenport, ASCE Transaction, 1961, Part II.

34) Distributions of Extreme Winds in the United States, H.C.S. Thom, ASCE Transaction, 1961, Part II.

9.0 SPECIAL INTERFACE

COLUMN TO FOOTING CONNECTIONS

The guideway column to footing connection is designed to provide a superior structural connection while simultaneously allowing rapid erection of the columns. The connection system allows a rough installation of the column using heavy construction equipment and fine adjustment of the column location with a small work crew.

The connection consists of corregated metal pipes being cast in the footing. These pipe later receive the reinforcing which is extended out from the base of the precast column. The pipes are long enough to develop a full tension connection with the column reinforcement. High strength concrete can be used to reduce the embedment length in the footing.

Erection bolts or other hardware are cast in the footing to allow temporary installation and adjustment of the column.

Drainage is accomplished by extending a drain pipe out of the base of the column. This pipe would slip into an oversized pipe in the footing. In this manner, connections to storm drains can be made directly through the footing. In those instances where the footing is below the storm drain, drain pipes will exit from the side of the column at the appropriate elevation. Refer to Figure 5.2.1.

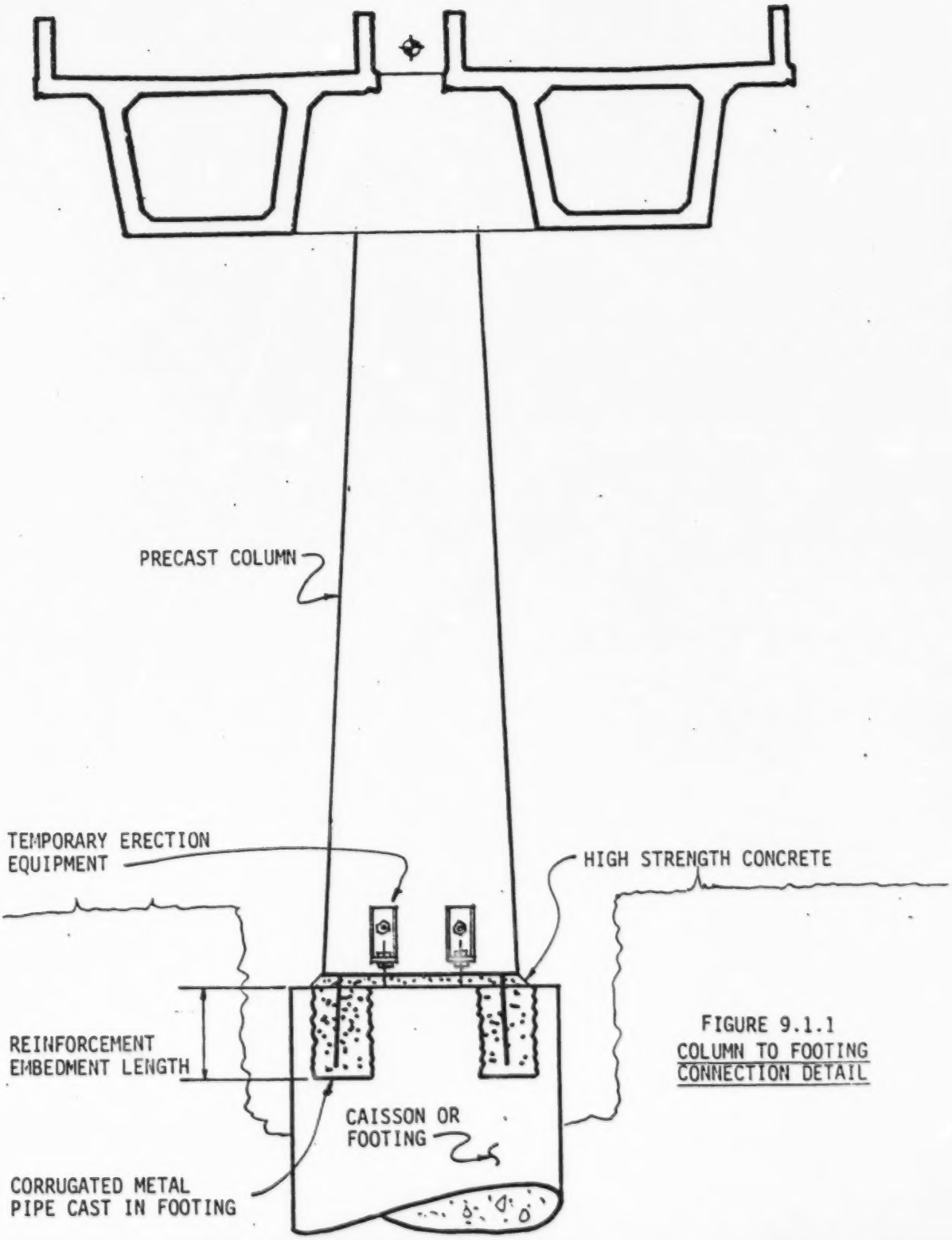

FIGURE 9.1.1
COLUMN TO FOOTING
CONNECTION DETAIL

PRELIMINARY COLUMN BASE LOADS AT FOOTING

ASSUMPTIONS:

Dual lane guideway
Two-span continuous structure.
Ultimate Load Case 3 for curves.
No relaxation due to column deflection.
$M_L = 0.25\ M_T$ (except tangent).
6 M height.

FIXED COLUMN (kips, ft)

FORCE	SPAN = 30 M TANGENT	SPAN = 26 M R = 150 M	SPAN = 18 M R = 35 M
V_{Trans}	80	275	500
P	1,000	800	700
M_{Trans}	3,000	10,000	16,000
M_{Long}	2,500	2,500	4,000

EXPANSION COLUMN (kips, ft)

FORCE	SPAN = 30 M TANGENT	SPAN = 26 M R = 150 M	SPAN = 18 M R = 35 M
V_{Trans}	80	175	325
P	900	700	060
M_{Trans}	2,500	4,500	8,500
M_{Long}	1,150	1,150	2,200